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(54) **Ultrasonic transducers for medical diagnostic examinations.**

(57) An ultrasonic probe for mechanical scan-type is disclosed which comprises one or a plurality of ultrasonic transducers mounted on a supporting member. One or more of the transducers are divided electrically or mechanically. The supporting member is located in a container with ultrasonic wave propagating medium. The supporting member rotates or swing in the container and ultrasonic beam emanated therefrom scans object in sector form. The divided transducers are selectively driven in commonly or separately in accordance with display mode.

Another embodiment which includes a plurality of ultrasonic transducers each having different focal length is also disclosed.

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This invention relates to ultrasonic probes for use in ultrasonic diagnostic systems, and more particularly to ultrasonic probes for producing mechanical sector scans in an object to be scanned.

In the medical fields, ultrasonic diagnostic systems have been widely used in recent years. The ultrasonic diagnostic system makes use of a variety of ultrasonic transducers. One example is the mechanical sector scan-type probe (hereafter called "MSP"), the piezoelectric transducer assembly of which is rotated or swung to obtain ultrasonic image in sector scan-type, is well known.

On the other hand, it is well known that the diagnostic information obtained by ultrasonic diagnostic systems are classified into 2D mode, M mode, and Doppler mode in accordance with display method or received signal.

In the 2D mode, ultrasonic pulse signals received by the piezoelectric transducer are displayed on a display device as one scanning line with brightness modulation. The scanning line is successively shifted in accordance with the received ultrasonic pulse signals to obtain a cross-sectional image of the object. When the shift of the scanning line is performed at high speed, a real time cross-sectional image of the object, such as a human body, is observed.

In the M mode, an ultrasonic wave is transmitted and received at a predetermined position, and the received signal is displayed as a brightness modulation signal in accordance with variation in time.

Doppler mode is a mode used to obtain the frequency spectrum and/or velocity of travelling space material in the object by receiving a ultrasonic signal which is frequency modulated or Doppler shifted by velocity of the travelling material. A continuous wave Doppler (hereafter called "CW Doppler"), which uses a continuous wave ultrasonic signal, has advantage enabling detection of high speed travelling materials but disadvantage not to be able to pick up information for a specified region. On the other hand, the pulse Doppler mode, which uses a pulsed ultrasonic signal, has the advantage of enabling detection of information for a specified region but has low detecting ability of high speed travelling material. Therefore, CW Doppler and pulse Doppler are selected to use properly.

In conventional MSP, 2D mode, M mode and pulse Doppler mode are obtained with one MSP by using transmitting and receiving circuit corresponding to each of the 2D mode, M mode, and pulse Doppler mode. On the other hand, CW Doppler mode information cannot be obtained with one MSP and an exclusive probe for CW Doppler is required. In this case, troublesome operation cannot be avoided because two probes for MSP and CW Doppler must be operated. Even if the two probes are attached to each other, the probe size becomes large and contact surface to the object (this is called foot print) becomes wide. The wide contact surface often fails to obtain necessary information for precise diagnosis of specific affected part of the human body.

In the mean time, conventional MSP generally employs a plurality of piezoelectric vibrators having some curvature and aperture to transmit and received converged ultrasonic beam. In this case, ultrasonic beam convergence is different along depth of the object. Therefore, resolution at the point near the surface of the object and the point far from the surface of the object is reduced because of the use of a thick ultrasonic beam. In particular, deterioration of the resolution at the region far from the surface of the object is one of severe problem to be solved in conventional MSPs.

SUMMARY OF THE INVENTION

It is, therefore, an object of the present invention to provide an MSP which is able to cope with all of 2D mode, M mode, CW Doppler and pulse Doppler mode with one MSP.

It is another object of the present invention to improve resolving power at near and far region from the surface of the object.

According to the present invention there is provided an ultrasonic probe comprising:

a plurality of piezoelectric elements mounted on a supporting member,

means for rotating or swinging said supporting member,

a container for containing said supporting member with ultrasonic wave propagating material, and

an acoustic window provided at container,

wherein said plurality of piezoelectric elements have different focal length with each other.

The divided piezoelectric vibrators are electrically connected or separated in accordance with 2D mode, M mode, CW Doppler mode and pulse Doppler mode.

In another embodiment an MSP is provided which comprises a plurality of ultrasonic transducers, each of which is mounted on a supporting means rotatable or swingable around an axis. Each of the transducer has a piezoelectric vibrator having a different focal length to the others.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be described in further detail with reference to the accompanying drawings, in which:

Fig. 1 is a schematic inner side view of an MSP

adaptable for the present invention;

Fig. 2 is a cross-sectional side view of a rotary-transformer portion of the MSP of Fig. 1;

Fig. 3 is a equivalent circuit of the MSP of Fig. 1;

Fig. 4 is a schematic inner side view of a first embodiment of the MSP according to the present invention;

Figs. 5a and 5b are front views of a ultrasonic transducer according to the present inventions;

Fig. 6 is a schematic inner side view of a second embodiment of the MSP according to the present invention;

Figs. 7a and 7b are side views of a rotor adaptable to the MSP of Fig. 6;

Fig. 8 is a schematic inner side view of a third embodiment of the MSP according to the present invention;

Figs. 9a and 9b are side views of ultrasonic beams obtained by the MSP of Fig. 8;

Figs. 10a and 10b are side views of ultrasonic beams of fourth embodiment of the MSP according to the present invention;

Figs. 11 and 12 are cross-sectional side views of a rotary transformer adapted to the MSP according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Referring to Figs. 1 and 2, piezoelectric vibrators 20a, 20b and 20c are mounted on a supporting member 14 which is rotatable around a axle 4 supported through bearing 40. At one end of the axle 40, a pulley 60 is provided for transmitting rotation of a motor 5 to the supporting member 14 through another pulley 80 and a belt 6. On both sides of the supporting member 14, rotary coils 30b and 31b are embedded or mounted. A fixed coil 30a is embedded or mounted on inner side wall of a container 2 in opposite relation to the rotary coil 30b. In the same manner, a fixed coil 31a is provided on a inner surface of a housing 55 in opposite relation to the rotary coil 30b. On one side wall of the pulley 60, a third rotary coil 32b is provided which is opposite to a fixed coil 32a mounted on another surface of the housing 55. The fixed coils 30a, 31a, 32a and the rotary coils 30b, 31b, 32b are formed in spiral. Numeral 33 designates a magnetic core. A set of the fixed coil 30a, the rotary coil 30b and the magnetic core 33 forms a first flat type rotary transformer. In the same manner, a set of the fixed coil 31a, the rotary coil 31b and the magnetic core 33, and a set of the fixed coil 32a, the rotary coil 32b and the magnetic core 33 form second and third flat type rotary transformers. Each of the rotary transformers is electrically coupled to the rotating piezoelectric vibrators 20a, 20b, and 20c with no contact relation.

The magnetic cores 33 are made of magnetic material such as ferrite to improve efficiency of the rotary transformer and suppress electro-magnetic interference between each of the rotary transformers. The electromagnetic interference between the rotary transformers is suppressed moreover by providing shielding plates 34 of magnetic material such as Permalloy between the rotary transformers. When the fixed coils 30a, 31a, 32a and the rotary coils 30b, 31b, 32b, are provided in such a manner that they are embedded on the surfaces of corresponding members, the thickness of the rotary transformers does not influence to the size of the container 2 and housing 55.

The supporting member 14 is rotated by the motor 5 through the pulley 80, the belt 6 and the pulley 60. The motor 5 is controlled to maintain constant rotation by rotation controller 7. The piezoelectric vibrators 20a, 20b, and 20c are provided on outside surface of the supporting member 14 having equi-angular relation of 120°, and each piezoelectric vibrator scans 90° sector region respectively. Each of the piezoelectric vibrators has single or multi-layered acoustical matching layers for matching acoustical impedance between the object as occasion demands. The inductance of the rotary transformers is also matched to the impedance of the piezoelectric vibrators 20a, 20b and 20c for the raising efficiency of transmitting and receiving ultrasonic wave.

Referring now to Fig. 3, when the piezoelectric vibrator 20a is rotated at predetermined position corresponding to the object, a pulse signal is supplied to the fixed coil 30a to excite the piezoelectric vibrator 20a. The pulse signal is immediately induced to the rotary coil 30b by electromagnetic induction and excites the piezoelectric vibrator 20a. As a result, the piezoelectric vibrator 20a generates a ultrasonic pulse beam. The ultrasonic pulse beam is emitted to the object through the container 2 which is filled with an ultrasonic wave propagating material 3. A reflected beam obtained by the difference of acoustic impedance of the object is received by the piezoelectric vibrator 20a along a reverse passage. The received signal is transmitted to the fixed coil 30a through the rotary coil 30b by electromagnetic induction and supplied to a signal processor via a cable 110. In the signal processor, the received signal is processed and displayed as a brightness signal of one scanning line on a cathode ray tube. In the same manner, the piezoelectric vibrators 20b and 20c perform sector scanning operation of a 90° sector.

The supporting member 14 rotates at a rotating speed of 10 rps and the piezoelectric vibrators 20a, 20b, and 20c are sequentially selected to be excited by switching the fixed coils 30a, 31a and 32a with a semiconductor switching device 90, which is

provided in the signal processor, in accordance with relative position of the piezoelectric vibrator 20a, 20b, and 20c to the object. As a result, 30 frames of sector scan-type section image are obtained per second.

Referring now to Fig. 4, an ultrasonic wave transmitting and receiving portion 1 comprises a piezoelectric vibrator, an acoustic impedance matching layer and a backing load member, which are integrated in a piled layer. The piezoelectric vibrator, or both of the piezoelectric vibrator and the acoustic impedance matching layer, are mechanically or electrically divided, as shown in Figs. 5a and 5b, into two regions by sound wave buffer member 11 formed of, for example, silicone rubber to decrease acoustic coupling between the two divided regions. The ultrasonic wave transmitting and receiving portion 1 of Fig. 4 employs the arrangement shown in Fig. 5a. If no acoustic crosstalks occur, only the electrode of the piezoelectric vibrator may be divided as illustrated in Figs. 5a and 5b. The thus obtained ultrasonic wave transmitting and receiving portion 1 is located in the container 2 which has an acoustic window made of resin having acoustic impedance matched with that of the human body such as poly-methylpentene. The container 2 is filled with the ultrasonic wave propagating material 3 such as deflated water or buntanediol. The ultrasonic transmitting and receiving portion 1 is swung around the axis 4 by a belt or crank chain 6 driven with a motor 5 The motor 5 is linked to a controller 7 with a belt or gear 8 to adjust the rotational speed of the motor 5 to a predetermined value. The controller 7 is a device such as rotary encoder or a potentiometer. Numeral 9 designates a housing of the MSP. In this embodiment, a lead wire 10a is connected to a common electrode of the piezoelectric vibrator, a lead wire 10b to an electrode of the piezoelectric vibrator I, a lead wire 10c to an electrode of the piezoelectric vibrator O respectively. The lead wires 10a, 10b and 10c are switched by a semiconductor switching device in a signal processing and displaying apparatus in accordance with the mode to be displayed. When 2D mode, M mode or pulse Doppler mode is displayed, the lead wires 10b and 10c are commonly connected. On the other hand, when the CW Doppler mode is displayed, one of the lead wires 10b and 10c is used exclusively for ultrasonic wave transmission and the other exclusively for ultrasonic wave reception. When the lead wires 10b and 10c are used in commonly connected the buffer region 11 does not influence to sound field because the buffer region 11 has very small area which is 30 to 100 times smaller than that of the divided ultrasonic transmitting and receiving portion.

Fig. 6 illustrates a second embodiment of the present invention. In Fig. 6, ultrasonic wave transmitting and receiving portion 1, container 2 having an acoustic window, ultrasonic wave propagating material 3, rotating axle 4, motor 5, belt or crank chain 6, controller 7 and housing 9 are same as those of Fig. 4. Reference numeral 12 designates a signal transmitter, 13a a connecting cable and 14 a supporting member, respectively. The MSP of Fig. 6 is essentially same as that of Fig. 1 except the divided ultrasonic wave transmitting and receiving portion 1. The ultrasonic wave transmitting and receiving portion 1 is based on the structure as shown in Figs. 5a and 5b, but other various modification may be employed.

Fig. 7a illustrates an example of the ultrasonic wave transmitting and receiving portion of Fig. 6. The supporting member 14 has a quasi-triangular cross-section on each of the plane surface of which one of three ultrasonic wave transmitting and receiving portions 1, each having constructions shown in Fig. 5a, are disposed. In this case, six signal transmission lines and one grounded line are connected to the signal processor and display apparatus through the signal transmitter 12. The signal transmitter 12 is formed with a rotary transformer which is the same as previously described, or a slip ring.

Fig. 7b is another example of ultrasonic wave transmitting and receiving portion. On one surface of the supporting member 14, the divided ultrasonic wave transmitting and receiving portion 1 is provided. On another surface of the supporting member 14, non-divided ultrasonic wave transmitting and receiving portion 15 is provided. When 2D mode, M mode or pulse Doppler mode is displayed, the ultrasonic wave transmitting and receiving portion 15 is used. When CW Doppler mode is displayed, the ultrasonic wave transmitting and receiving portion 1 is in the same manner as previously described.

Referring to Fig. 8, piezoelectric vibrators 20a, 20b and 20c each having the same aperture and different focal distances f_1, f_2 and f_3, respectively, are provided on surfaces of a supporting member 14 in equi-angular relation. The supporting member 14 is rotated by a DC motor 23 through a gear or a belt 24. The supporting member 14 is located in a container 2 having acoustic window made of polymethylpentene resin. The container 2 is filled with ultrasonic wave propagating material 3 such as deflated water. The piezoelectric vibrators 20a, 20b, and 20c are electrically connected to a signal processing and displaying apparatus 17 through a signal transmitter 16 such as a rotary transformer or a slip ring. An encoder 18, which is driven by the DC motor 23 through a gear or a belt 19, is provided for controlling the rotation of the supporting member 14. The signal transmitter 16, DC

motor 23, and the encoder 18 are connected to the signal processing and displaying apparatus 17 through connecting wires 10. Numeral 55 designates a housing of the MSP. The signal processing and displaying apparatus 17 generates transmission signals, processes received signals by amplifying, detecting, storing and scan converting signals, generates controlling signals for various subsystems, and displays the section image on a cathode ray tube. Generally, this signal processing is not performed in the MSP.

Referring to Fig. 9a, an ultrasonic beam from the piezoelectric vibrator 20a having focal length of f_1 is shown by dotted line. In the same manner, an ultrasonic beams from the piezoelectric vibrator 20b having focal length of f_2, and the piezoelectric vibrator 20c having focal length f_3, are shown by different dotted lines. In consideration of these, the piezoelectric vibrators 20a, 20b and 20c are selectively used in such a manner that most slender beam is selected. Namely, the piezoelectric vibrator 20a is used at Z_1 region, the piezoelectric vibrator 20b is used at Z_2 region, and the piezoelectric vibrator 20c is used at Z_3 region. Fig. 9b shows the ultrasonic beam thus obtained. As apparent from Fig. 9b, a converged slender beam is obtained according to the embodiment of Fig. 8.

The selection of desired ultrasonic beam is performed by the signal processing and displaying apparatus 17. In a first scanning operation, the piezoelectric vibrator 20a is selected to extract and memorize information in the Z_1 region. In a second scanning operation, the piezoelectric vibrator 20b is selected to extract and memorize information in the Z_2 region. In a third scanning operation, the piezoelectric vibrator 20c is selected to extract and memorize information in the Z_3 region. As a result, one section image to be displayed is obtained by three scanning operations. When the supporting member 14 is rotated at a speed of 600 rpm, a period of 100 msec is necessary to obtain one frame of a section image, and a section image of sector scan-type having frame rate of 10Hz is obtained.

Referring to Fig. 10a, the piezoelectric vibrators 22a, 22b, and 22c have different focal lengths f_1, f_2, f_3 and different apertures. In this embodiment, resolution in the Z_1 region is improved by using the piezoelectric vibrator 22a having a small aperture. The ultrasonic beam obtained by the embodiment of Fig. 10a is illustrated in Fig. 10b.

Referring now to Fig. 11, another embodiment of an ultrasonic cell is illustrated. A first coil 42 mounted on inner sidewall of a cell 32 and a second coil 43 mounted on a supporting means 14 form two pairs of rotary transformers having coil gaps of d_1 and d_2 respectively. The supporting member 14 is supported in the cell 32 by bearings 81 and 82. The bearing 81 is stored in a bearing box 83. On outside of the bearing box 83 and corresponding surface of the cell 32, a screw-cuttings having very small pitch are formed. The screw-cuttings make it possible to adjust the location of the supporting member 14, whereby the coil gaps d1 and d_2 are adjustable. In this case, another bearing 82 is suspended by a spring 84 which absorbs the change of thrust load occurring by adjusting the supporting member 14, and prevents oscillation of axis of the supporting member 14. Numeral 85 designates an oil seal.

The sum $d_1 + d_2$ of the coil gaps of the rotary transformer is decided by rotor length LR of the supporting member 14 and inner size LS of the cell 32 and cannot be adjusted itself. However, it is possible to adjust each of the coil gap d of the rotary transformer to a value equal to $(d_1 + d_2)/2$ by screwing the bearing box 83. Practically, the coil gap d is detected by measuring impedance of rotary transformer block. Therefore, electrical characteristics of the rotary transformer block can be regulated by screwing the bearing box 83.

When three ultrasonic vibrators are employed, a third coil 631 is further provided on a pulley 60 and chassis 83 in face to face manner as shown in Fig. 12. Impedance adjustment of the coil 631 is performed after adjusting two pair of coils of Fig. 11 described before.

Claims

1. An ultrasonic probe comprising:
   a plurality of piezoelectric elements mounted on a supporting member,
   means for rotating or swinging said supporting member,
   a container for containing said supporting member with ultrasonic wave propagating material, and
   an acoustic window provided at container,
   wherein said plurality of piezoelectric element have different focal length with each other.

2. An ultrasonic probe as claimed in claim 1, wherein said piezoelectric elements have apertures in such a manner that the shorter the focal length is, the smaller the aperture is.

3. An ultrasonic probe as claimed in claim 1 or 2, further comprising same number of rotary transformers as that of the piezoelectric elements, said rotary transformer comprises a rotary coil provided on side surface of said supporting member and a fixed coil oppositely located to said rotary coil.

4. An ultrasonic transducer as claimed in claim 3, wherein said rotary transformer further comprises means for adjusting the location of said supporting member in an axial direction thereof.

Fig.1

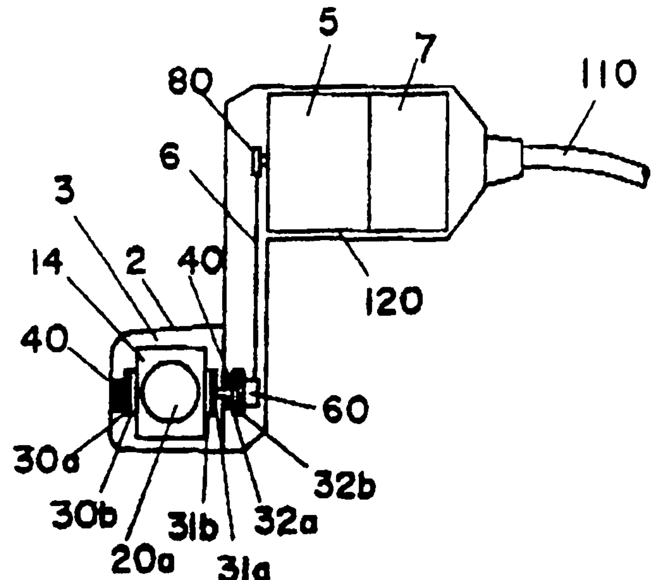

Fig.2

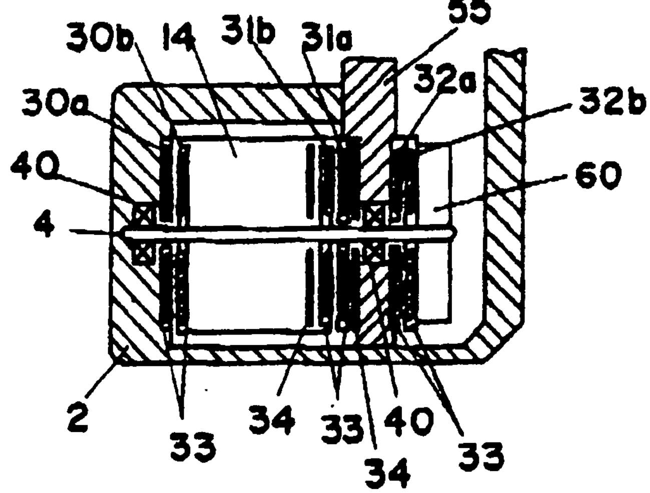

Fig.3

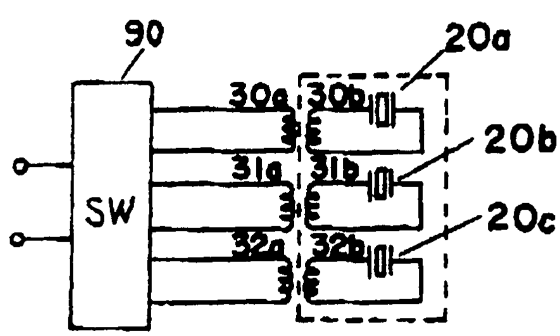

Fig. 4

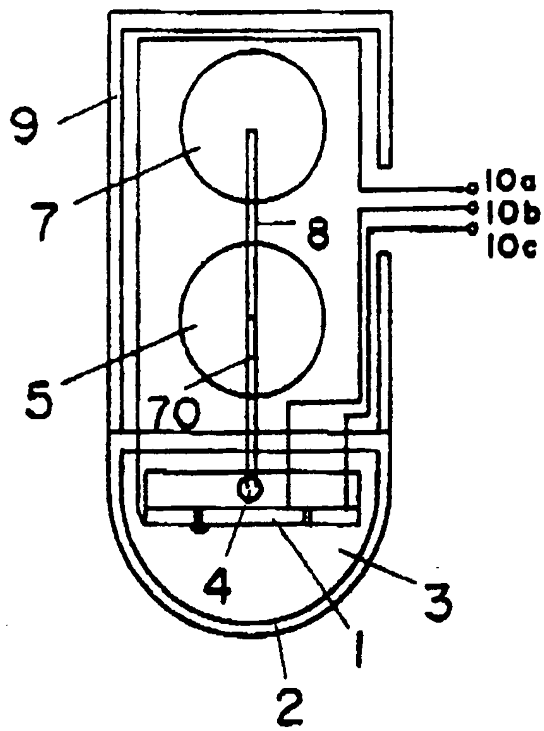

Fig.5a

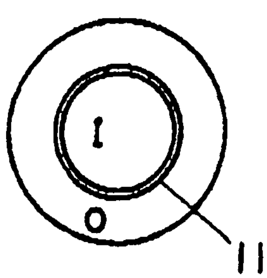

Fig.5b

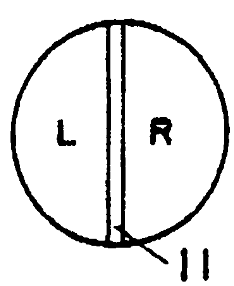

Fig. 6

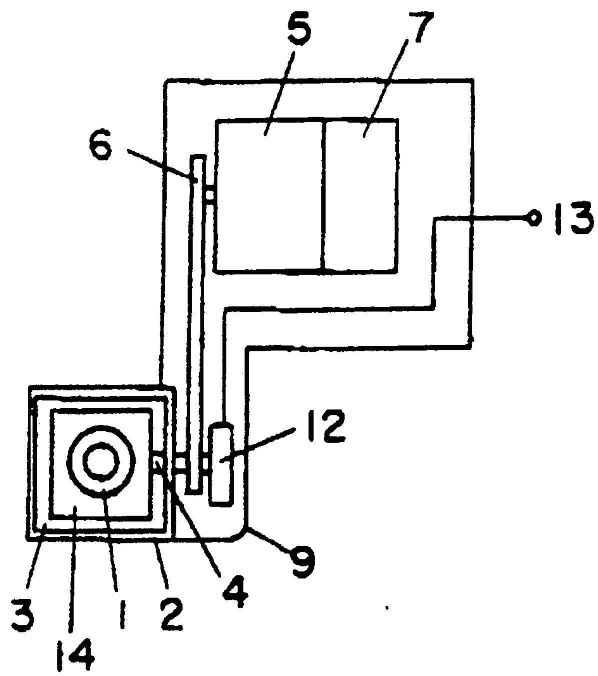

Fig. 7a

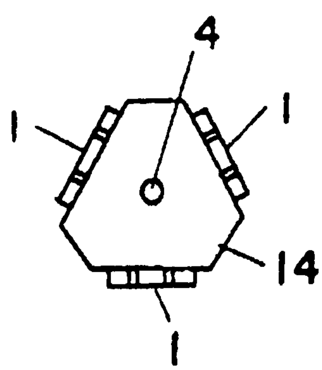

Fig. 7b

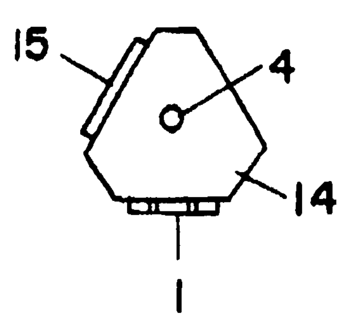

Fig. 8

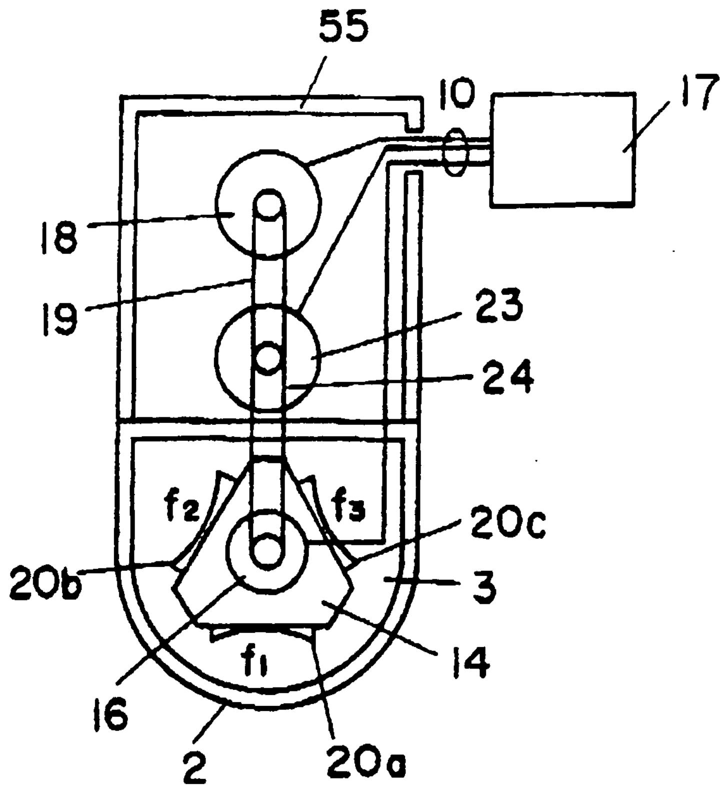

Fig. 9a

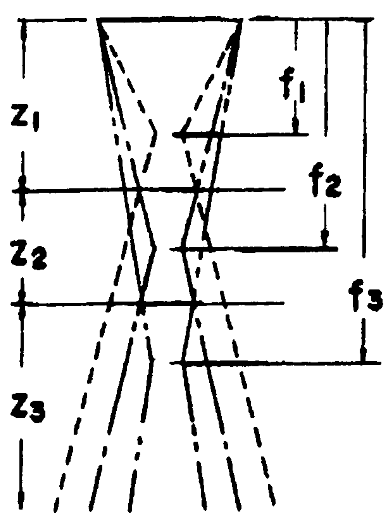

Fig. 9b

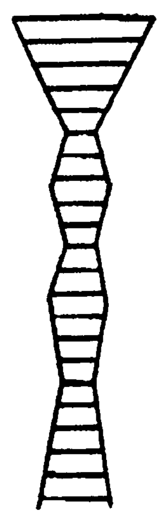

Fig.10a

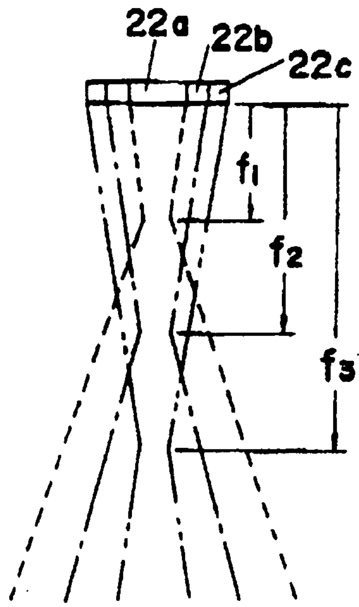

Fig.10b

Fig. 11

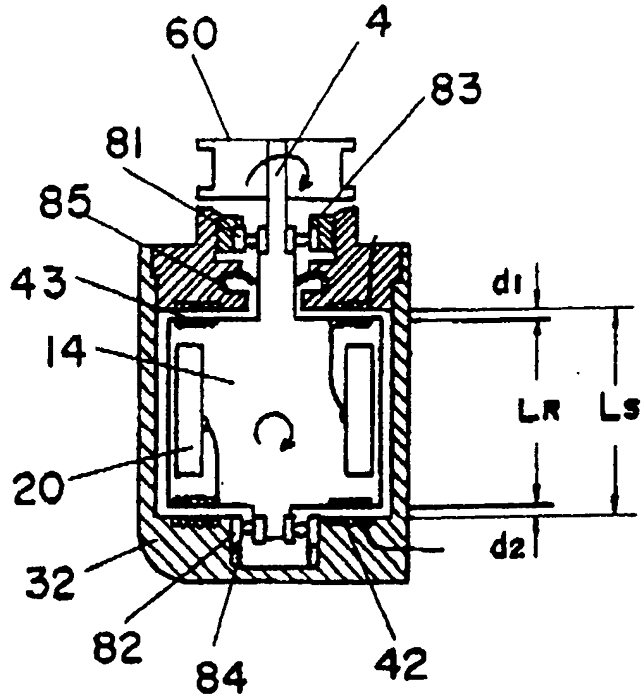

Fig. 12